Searches for Heavy Higgs in ATLAS (non-MSSM)

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Higgs Couplings 2016

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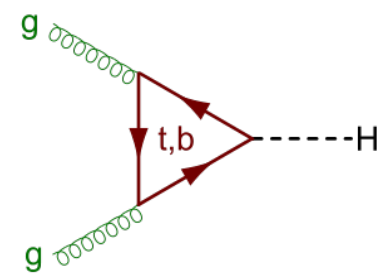
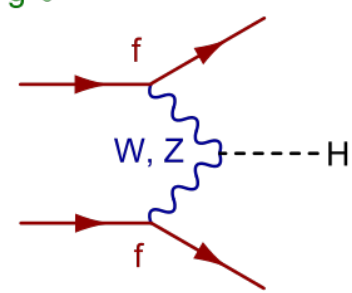
Introduction

- Heavy Higgs bosons are predicted in many BSM models
- Two examples are:
  - Two Higgs Doublet Model (2HDM): h, H, A, H^+, H^-
  - EW Singlet Model: h, H
- Report here on diboson searches - these are performed in fairly model independent ways:
  - Narrow Width Approximation (NWA)
    - 4 MeV (width << detector resolution)
  - Large Width Assumption (LWA)
    - with widths up to 15% of the mass (no interference treatment)
  - Production modes:
    - gluon-gluon fusion (ggF)
    - vector boson fusion (VBF)

ggF



VBF

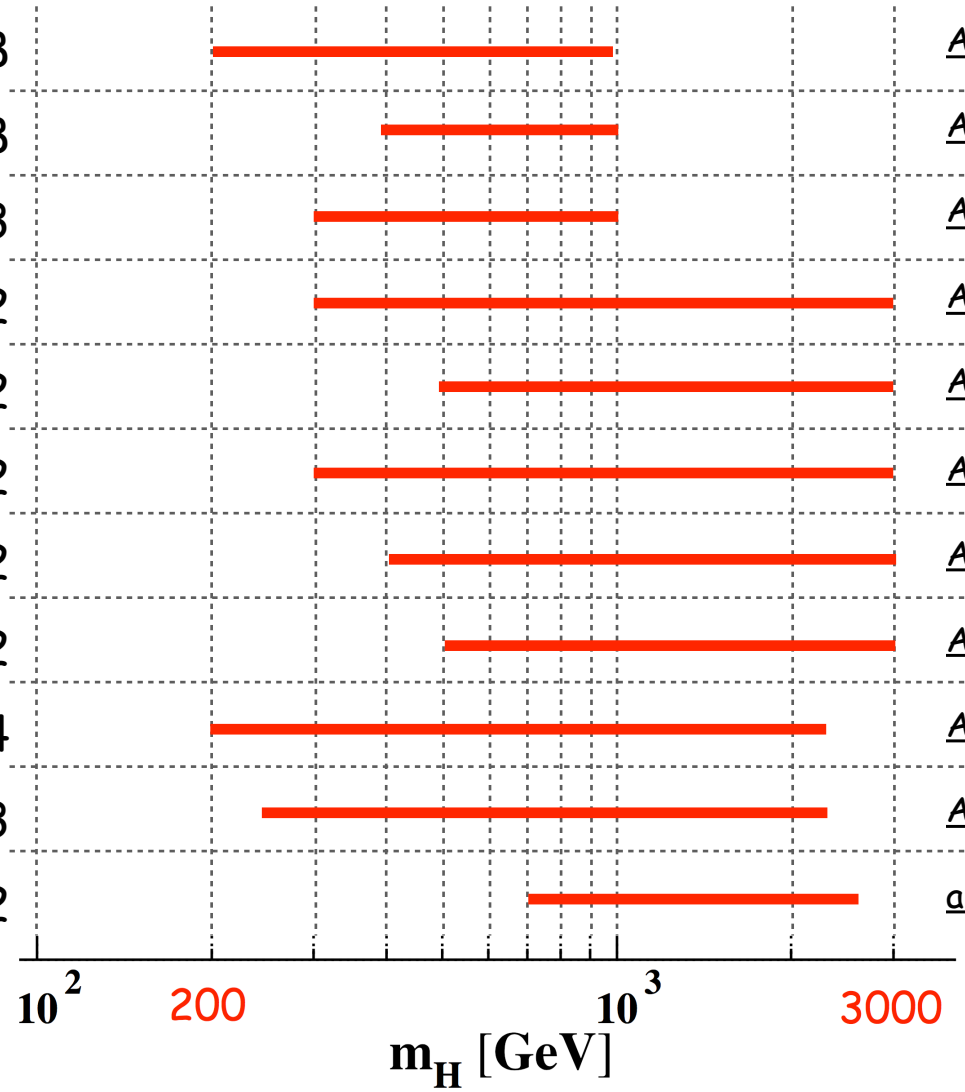


- Using the latest 13 TeV data sets of 2015 + 2016
  - sensitivity is often exceeding results published with 7/8 TeV data and extends to higher mass range

Overview of diboson modes and mass range

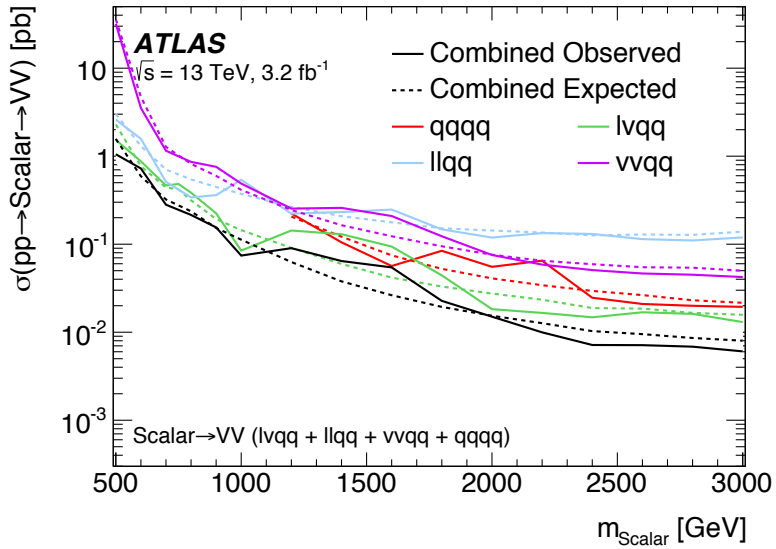
Channel	Lumi (fb^{-1})	Ref
ZZ→4l NWA	14.8	ATLAS-CONF-2016-079
LWA	14.8	ATLAS-CONF-2016-079
ZZ→llνν NWA	13.3	ATLAS-CONF-2016-056
ZZ→llqq NWA	13.2	ATLAS-CONF-2016-082
ZZ→ννqq NWA	13.2	ATLAS-CONF-2016-082
WW→lνlν NWA	13.2	ATLAS-CONF-2016-074
LWA	13.2	ATLAS-CONF-2016-074
WW→lνqq NWA	13.2	ATLAS-CONF-2016-062
γγ NWA/LWA	15.4	ATLAS-CONF-2016-059
Zγ→llγ NWA	13.3	ATLAS-CONF-2016-044
Zγ→qqγ NWA	3.2	arXiv:1607.06363

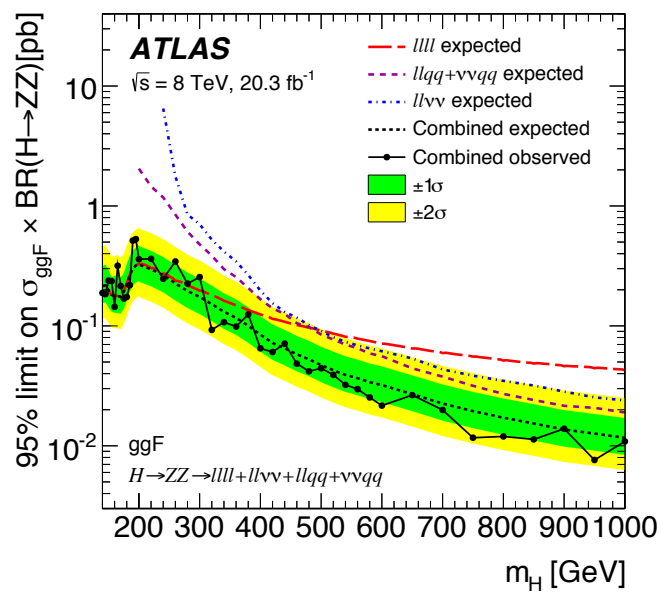
Mass range



Sensitivity Comparison for Different Modes

- Compare hadronic and semi-leptonic final states for 13 TeV, 3.2 fb^{-1} (arXiv:1606.04833)
  - Approx ordering: lvqq / qqqq / llqq+vvqq
  - Decays modes have no overlap
  - All but qqqq updated here with higher integrated luminosity
- Compare H→ZZ modes for 8 TeV, 20.3 fb^{-1} (EPJC)
  - 4l best below ~500 GeV
  - llvv close to llqq+vvqq





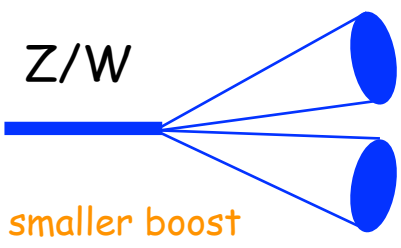
General Search Strategy

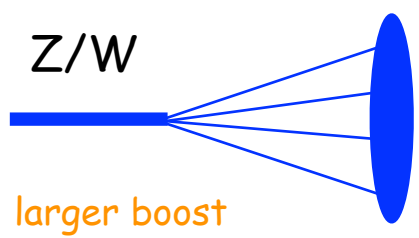
- Optimized event selection for a given heavy Higgs boson signal
- Data-driven background estimation/control for dominant backgrounds whenever possible
- Statistical analysis based on either fully reconstructed mass m_H or transverse mass m_T distributions from signal (and control) regions
- Hadronic Z/W decays reconstructed with

resolved small-R (ΔR=0.4) jet at low mass

merged large-R (ΔR=1) jet at high mass

Use energy correlation ratio $D_2^{(\beta=1)}$ to infer two-prong jet substructure

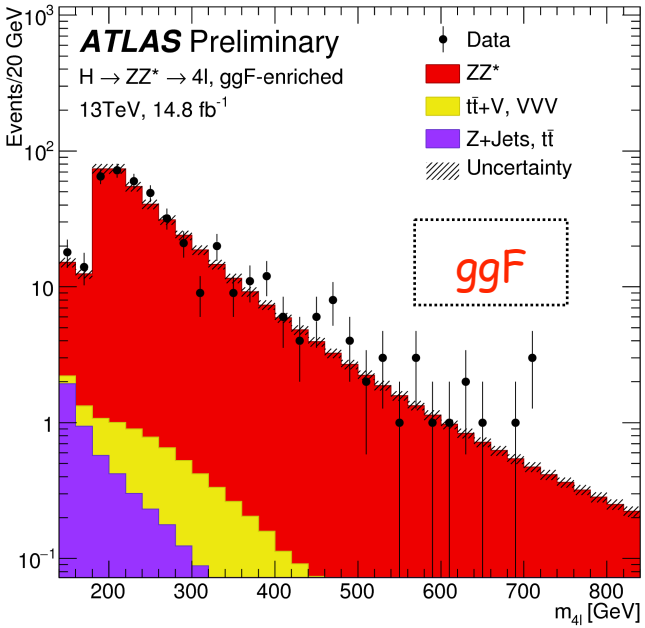


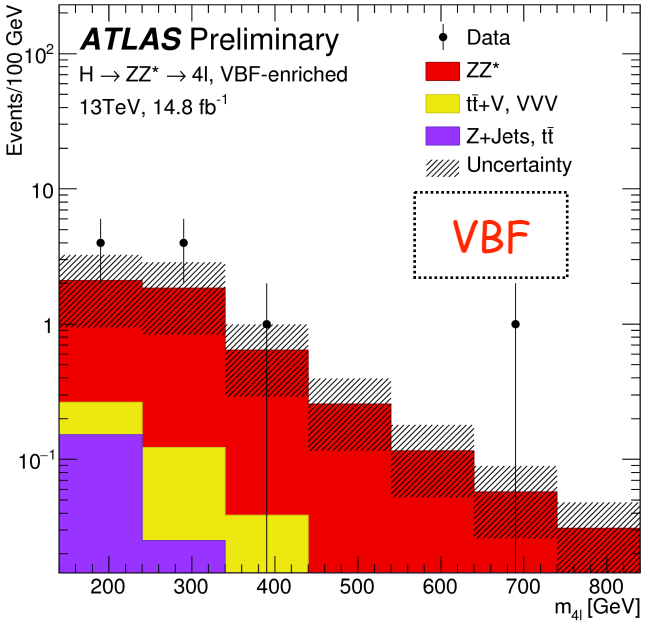


ATL-PHYS-PUB-2015-033

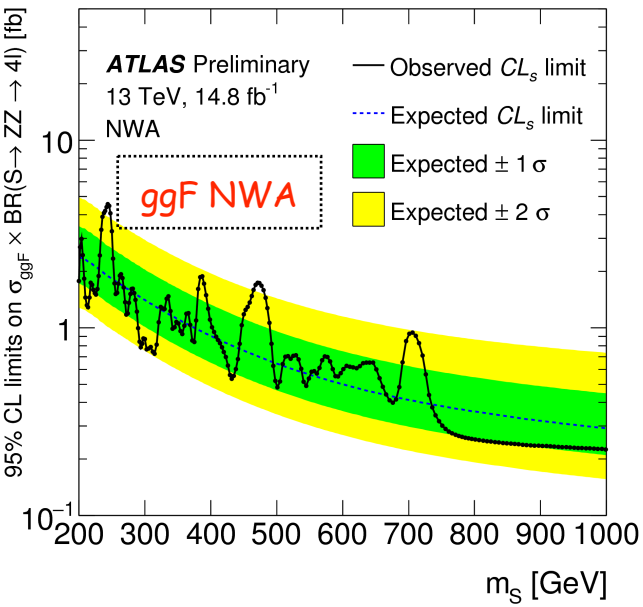
Decay mode with fully reconstructed leptons

- ZZ→4l (4μ, 2e2μ, 4e)
  - m_{4l} (apply Z mass constraint)
  - ⇒ excellent mass resolution
- ggF & VBF for NWA signal
- LWA signal (1%, 5%, 10%)
- 4 signal categories
  - VBF: m_{jj} > 400 GeV, $|\Delta\eta_{jj}|$ > 3.3
  - otherwise ggF (4μ, 2e2μ, 4e)
- Dominant background:
  - non-resonant ZZ*



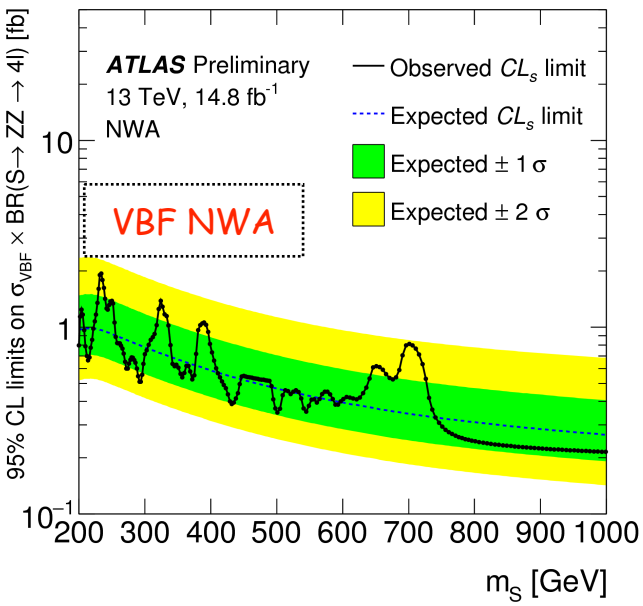


Decay mode with fully reconstructed leptons

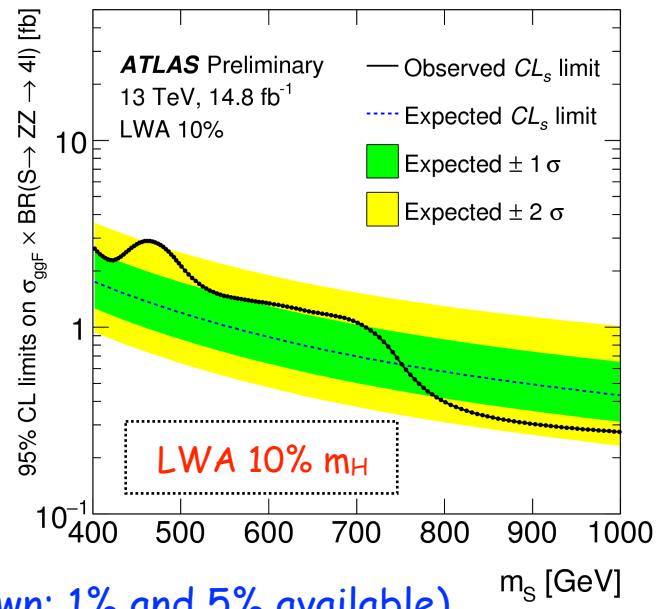


95% CL upper limits on σ × B(H→ZZ)

NWA valid for models with width < 0.5%



When fitting ggF, VBF is left free, and vice-versa



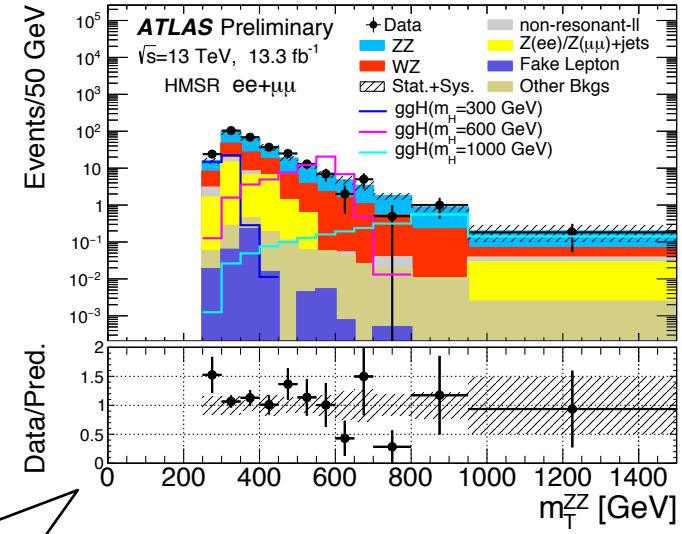
(Unshown: 1% and 5% available)

Leptonic Decay Modes with Neutrinos

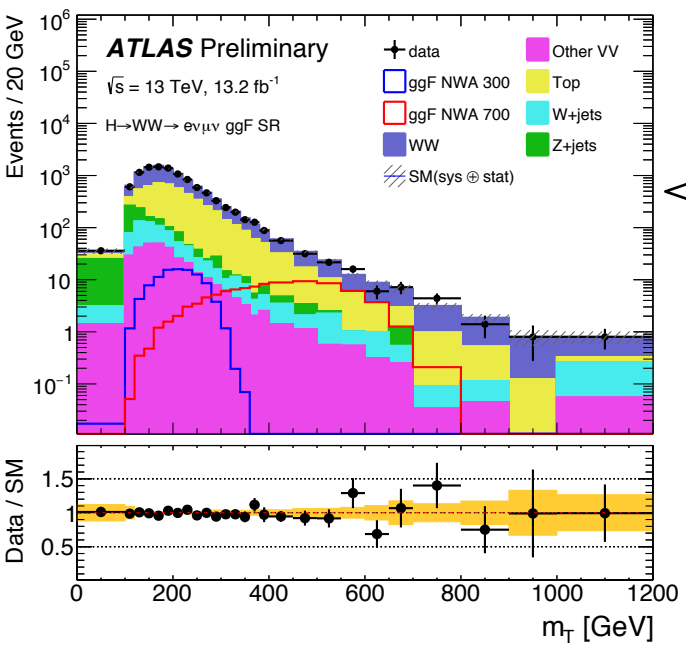
- ZZ→llνν, WW→lνlν
  - Cannot be fully reconstructed
  - Use m_T instead:

$$m_T^{ZZ} = \sqrt{\left(\sqrt{m_Z^2 + |p_T^{\ell\ell}|^2} + \sqrt{m_Z^2 + |E_T^{\text{miss}}|^2}\right)^2 - |\vec{p}_T^{\ell\ell} + \vec{E}_T^{\text{miss}}|^2}$$

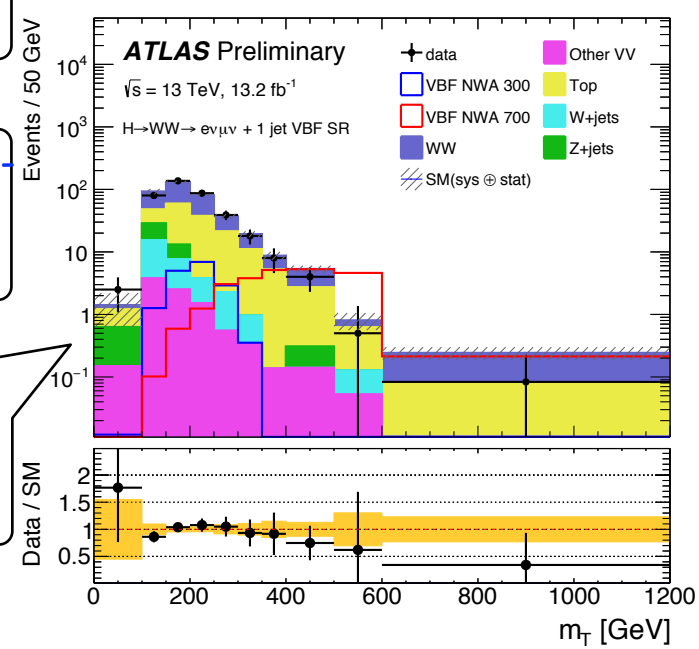
$$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{\text{miss}} \left[1 - \cos\Delta\phi\left(p_T^{\ell\ell}, E_T^{\text{miss}}\right)\right]}$$



ZZ signal region (SR)



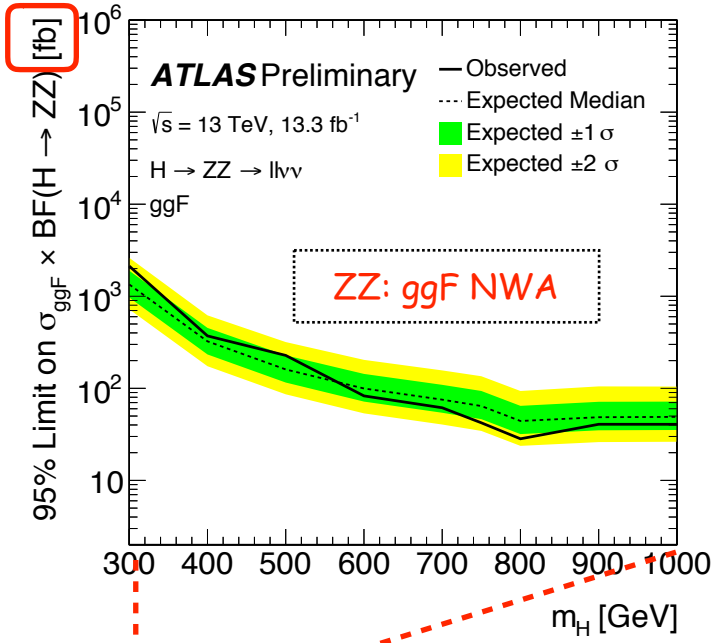
WW SR for quasi-inclusive ggF
new for ICHEP

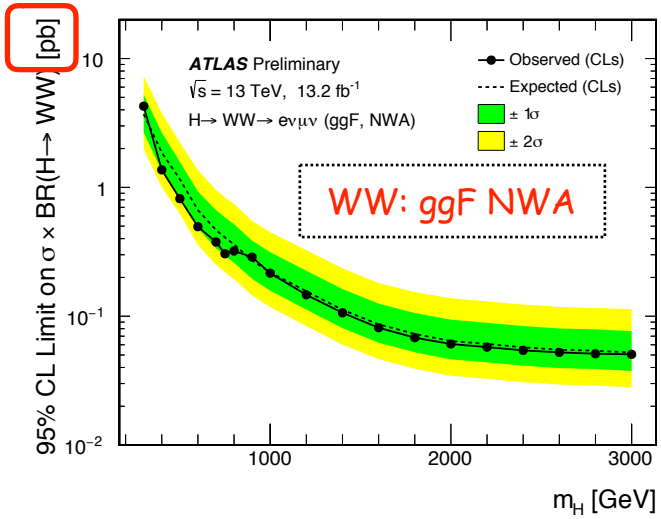


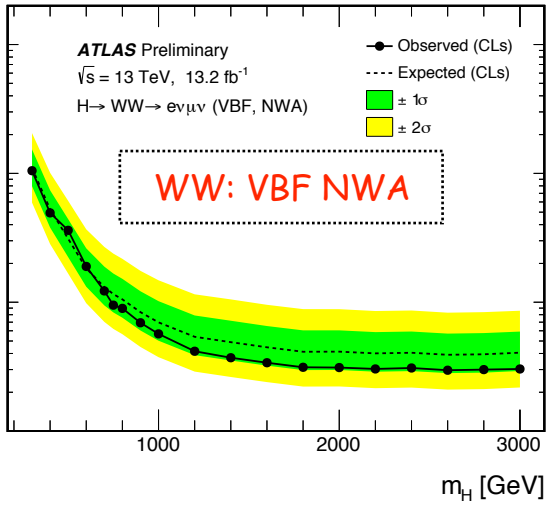
WW SR for 1-jet VBF
new for ICHEP

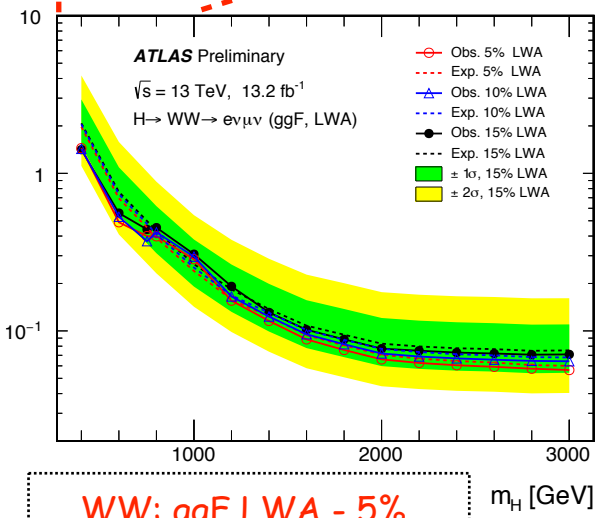
Leptonic Decay Modes with Neutrinos

95% CL upper limits on
$\sigma \times B(H \rightarrow ZZ/WW)$





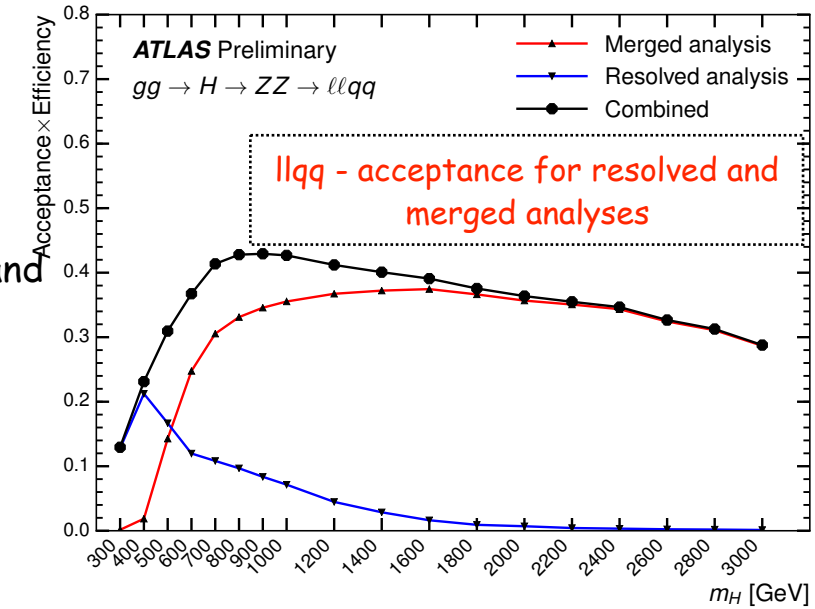


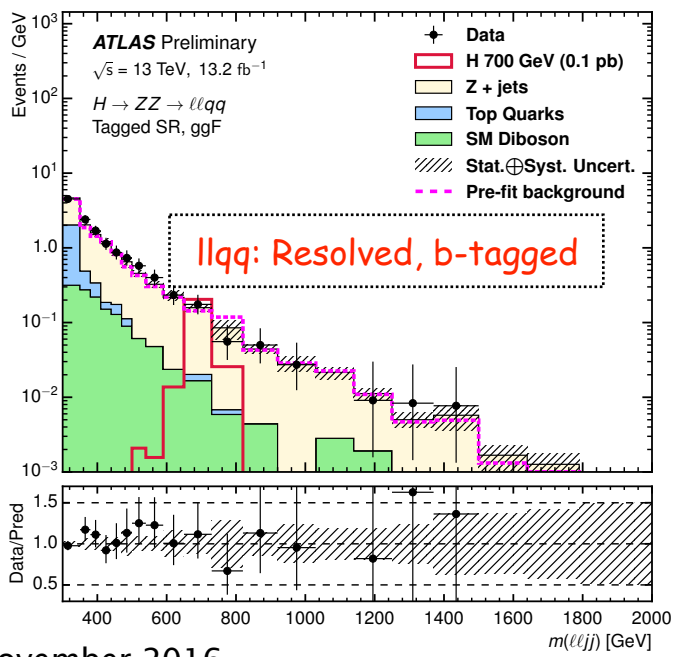


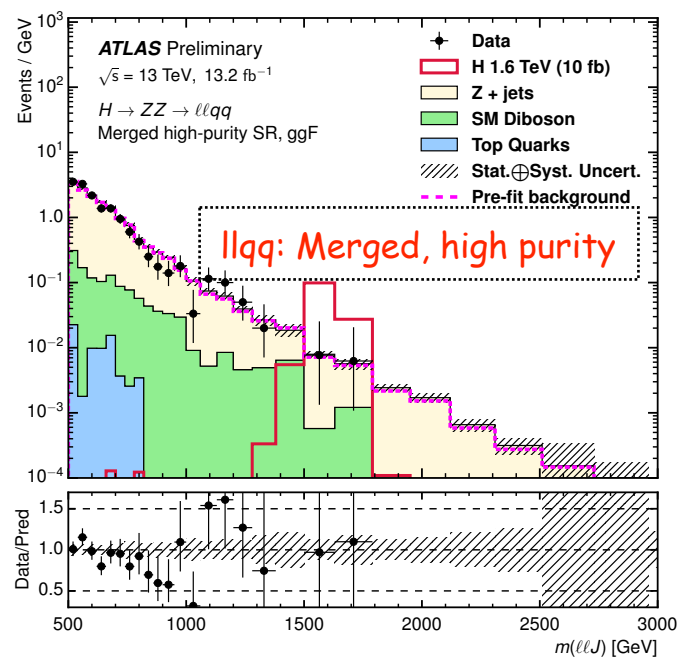
WW: ggF LWA - 5%, 10%, 15% x m_H

Semi-Hadronic Decay Modes

- ZZ→llqq, vvqq, WW→lvqq
  - llqq: resolved and merged jets
  - vvqq, lvqq: merged jet only
  - Resolved jet analysis subdivided into b-tagged and untagged categories
  - Merged jet analysis has two categories:
    - 1) High-purity: two-prong substructure
    - 2) Low-purity: otherwise
  - llqq VBF: m_{jj} > 600 GeV, $|\Delta\eta_{jj}|$ > 3.1



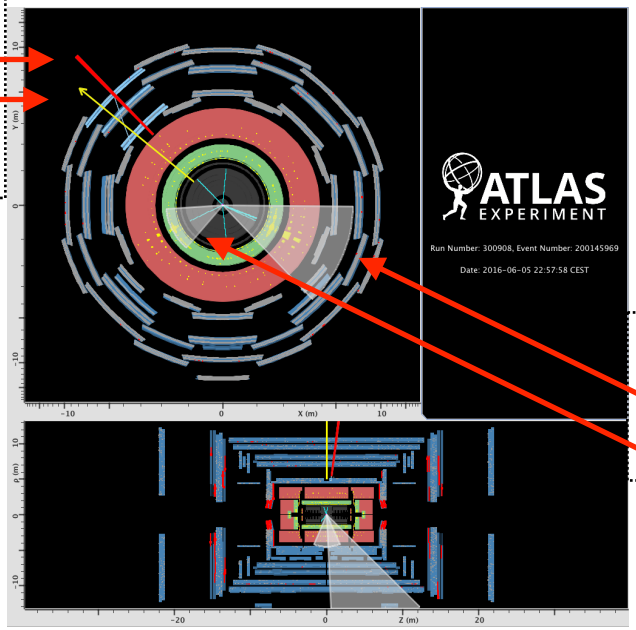




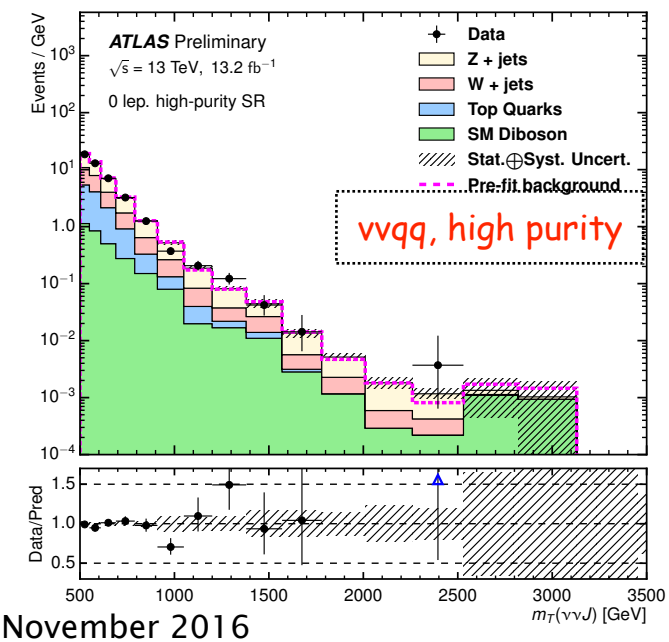
Semi-Hadronic Decay Modes

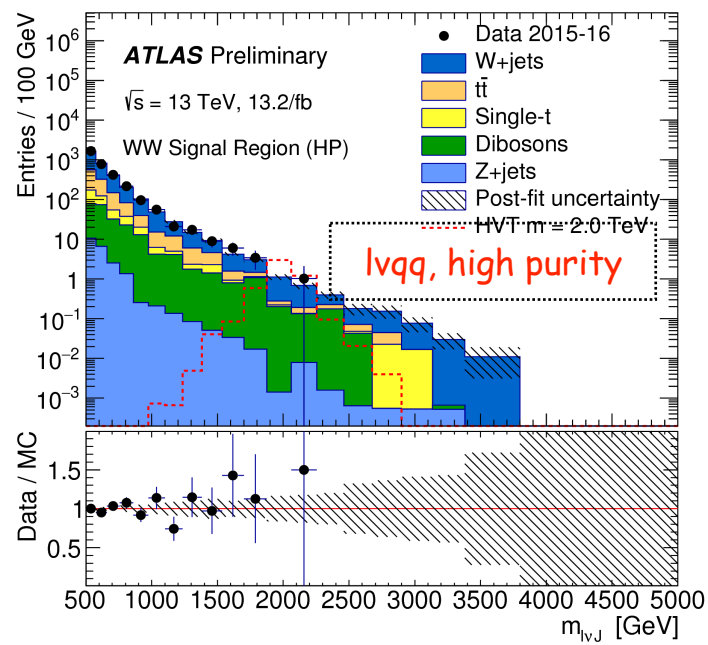
- ZZ→llqq, vvqq, WW→lvqq
  - llqq: resolved and merged jets
  - vvqq, lvqq: merged jet only
  - Resolved jet analysis subdivided into b-tagged and untagged categories
  - Merged jet analysis has two categories:
    - 1) High-purity: two-prong substructure
    - 2) Low-purity: otherwise
  - llqq VBF: m_{jj} > 600 GeV, $|\Delta\eta_{jj}|$ > 3.1

lvqq
E_T^{miss}=460 GeV,
p^T_μ=270 GeV
m_{lvJ}=1.56 TeV

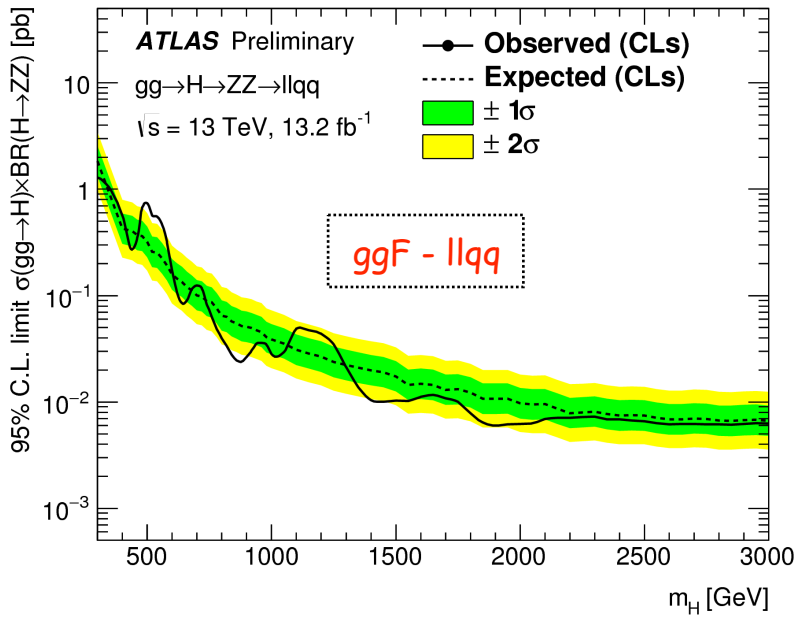


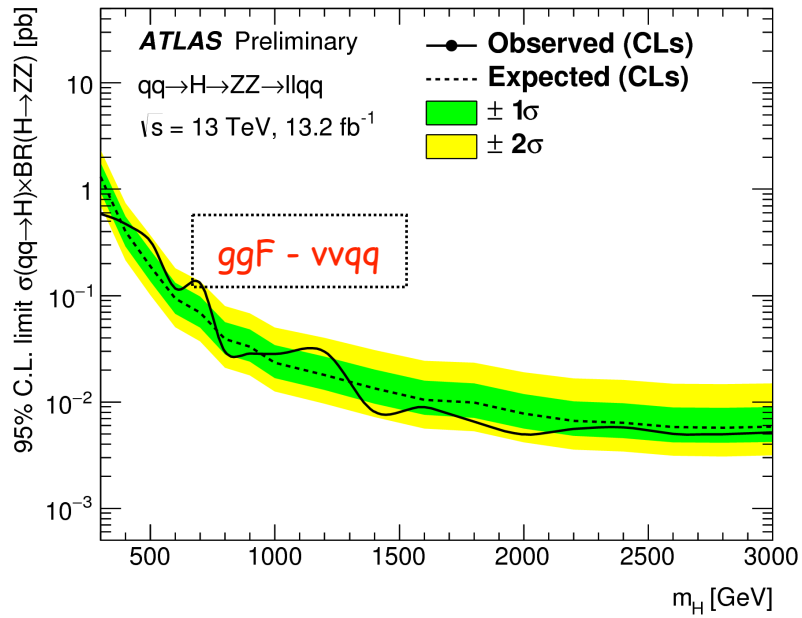
jet p_T:
810 GeV
270 GeV

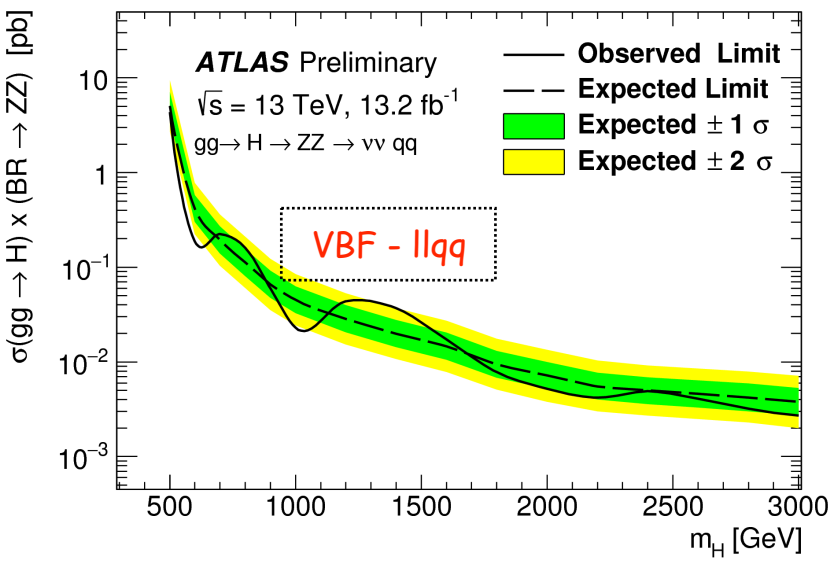


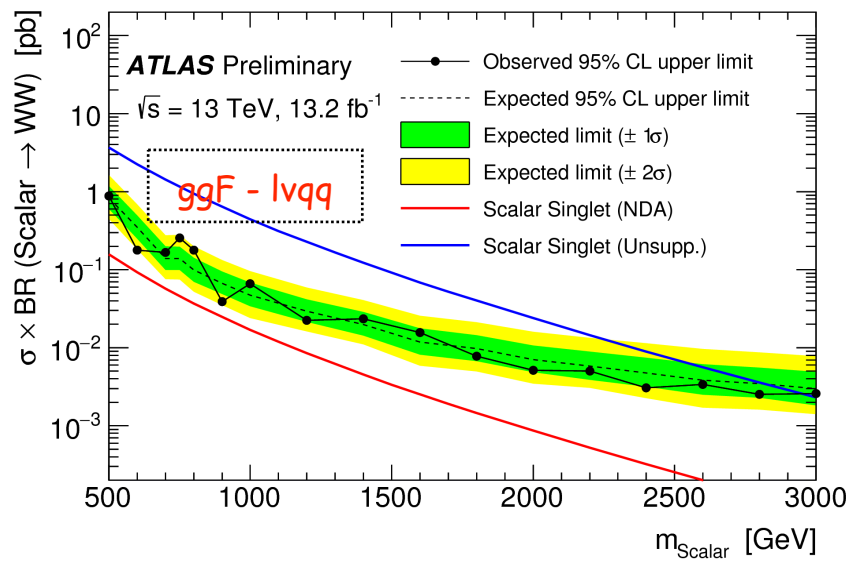


Semi-Hadronic Decay Modes (95% CL upper limits)



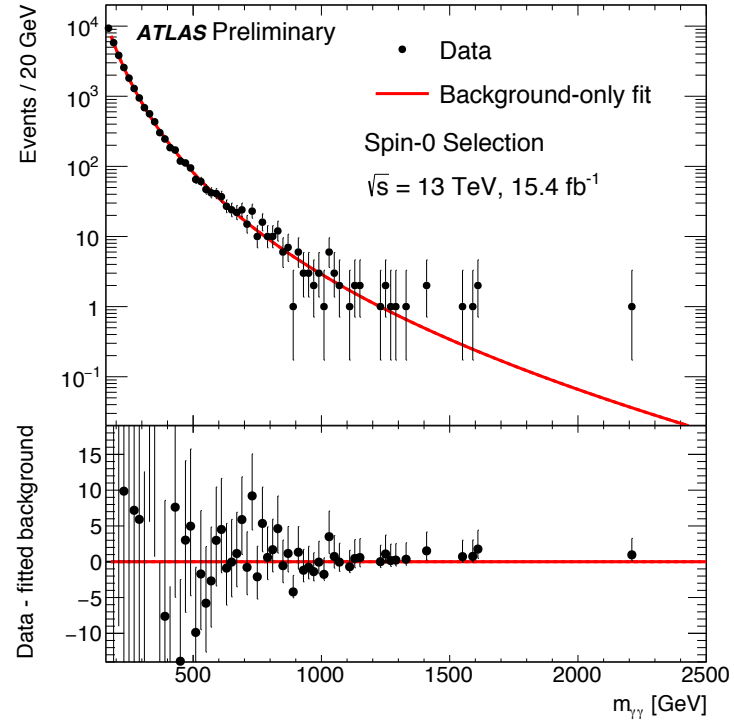


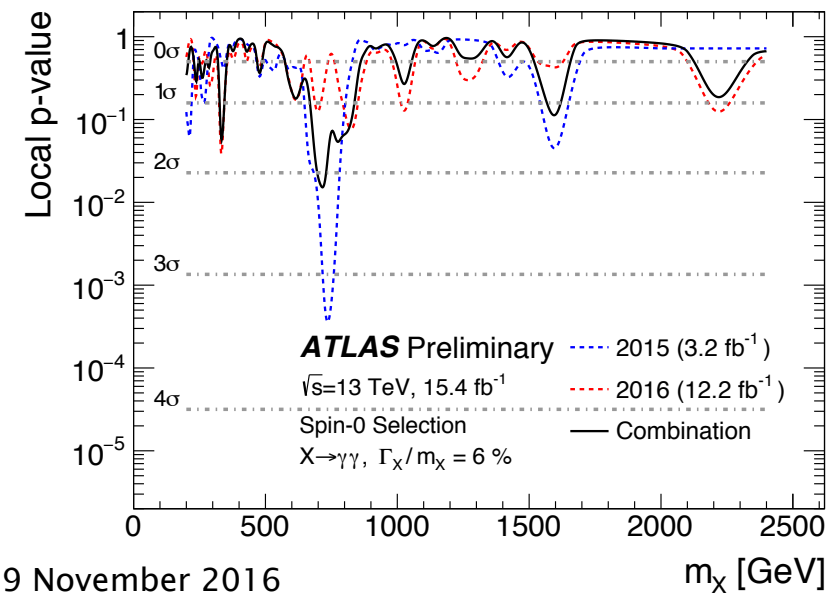


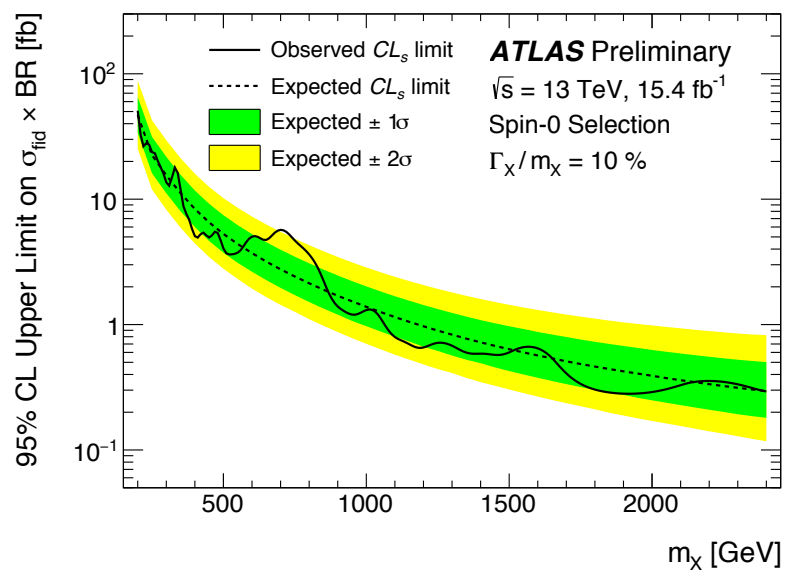


Diphoton Decay Mode

- Excess seen in 2015 dataset (3.2 fb^{-1}):
  - With reprocessing (energy and track reco):
    - Excess change: 3.9σ → 3.4σ
    - $m_{\gamma\gamma}$ ($\Gamma_{\gamma\gamma}$): 750 GeV (6%) → 730 GeV (8%)
- No excess seen in 2016 data (12.2 fb^{-1})
- 2015+2016 combined limits:
  - Widths evaluated: NWA, 2%, 6%, 10%
  - Largest excess near 750 GeV:
    - 2.3σ @ 710 GeV (10% width)



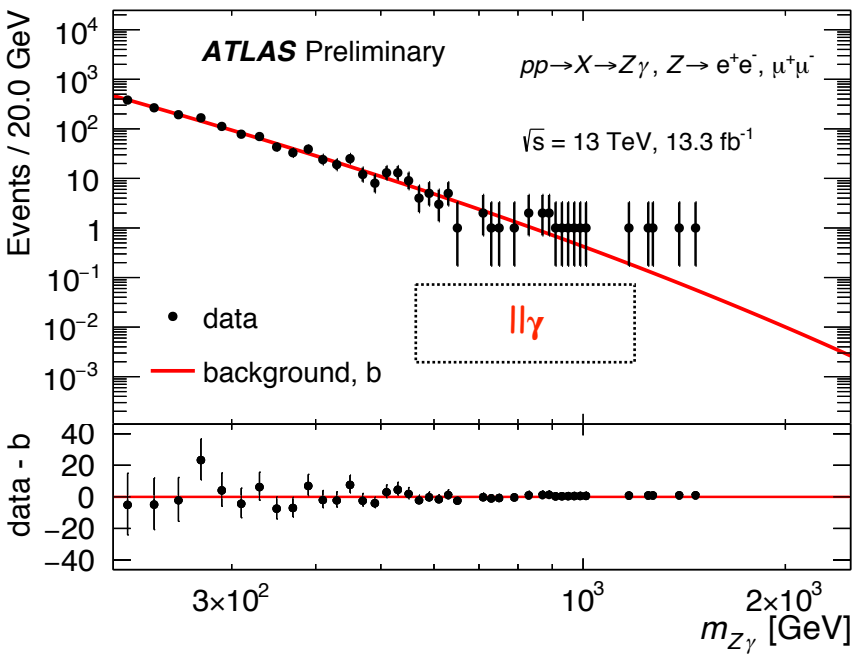


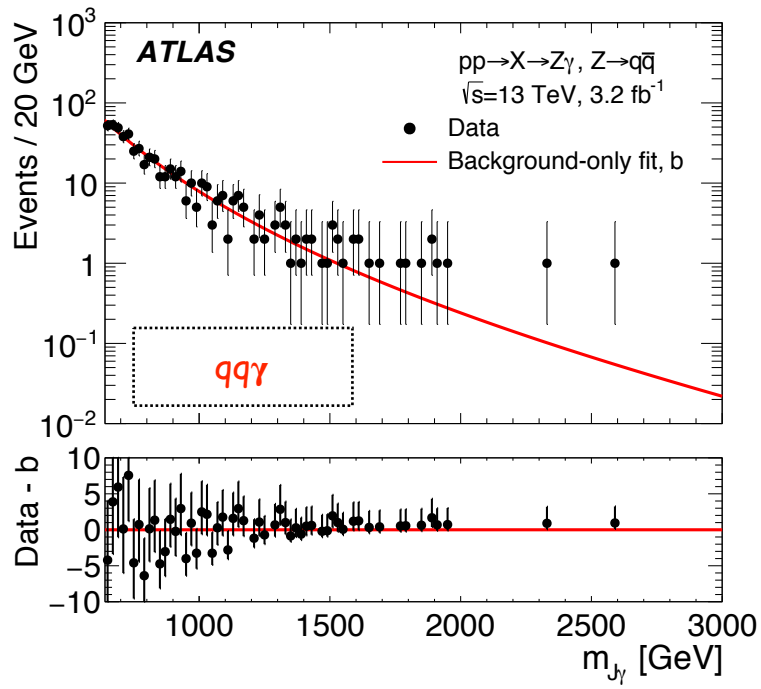


Z + γ Decay modes

- Zγ→llγ (13.3 fb^{-1}), qqγ (3.2 fb^{-1} published)
  - qq is a large-R (boosted) jet
- Dominant backgrounds:
  - llγ: non-resonant Z+γ (90%) + Z+jets (10%)
  - qqγ: γ +jets
  - Modeled with: $f_{\rm bkg}(m_{Z\gamma}) = \mathcal{N}(1-x^k)^{p_1+\xi p_2} x^{p_2}$

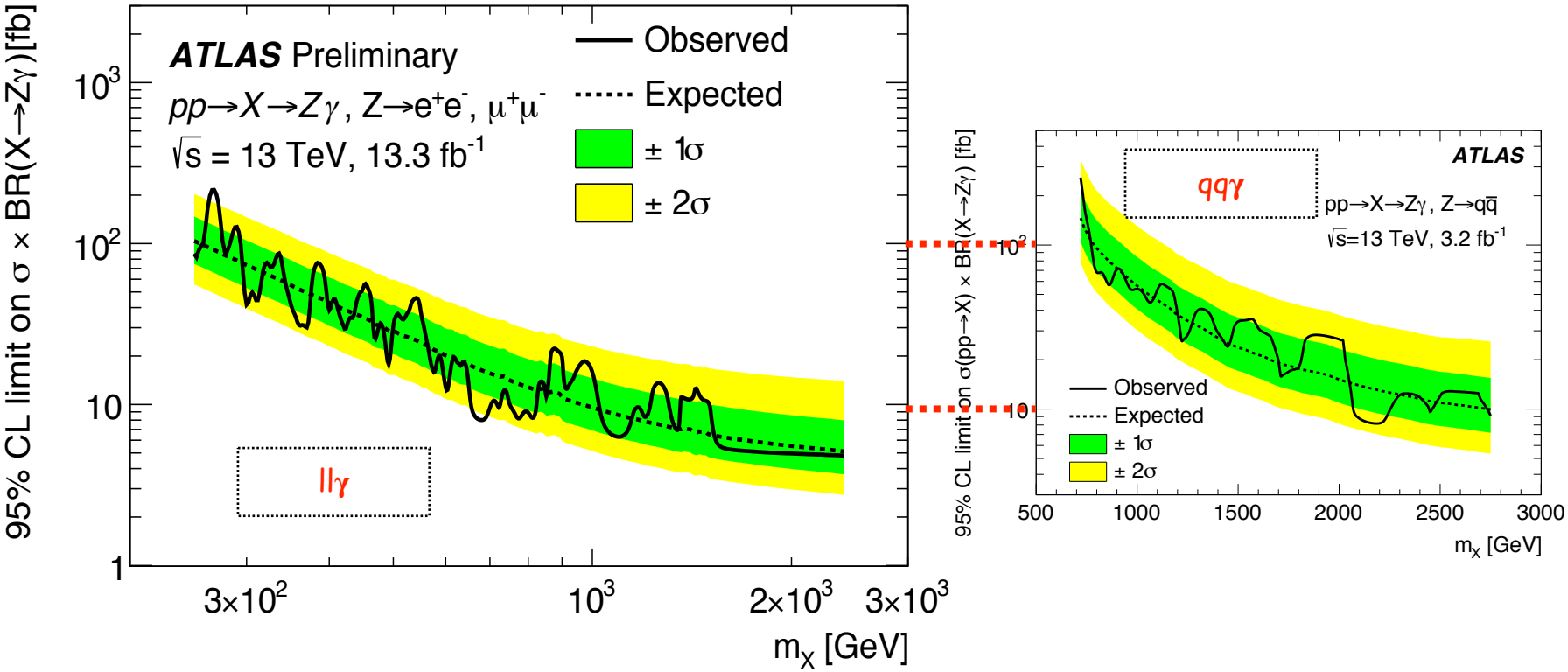
$$x = m_{Z\gamma}/\sqrt{s}$$
$$k = 1/3, \quad \xi = 0 \quad \text{for } ll\gamma$$
$$k = 1, \quad \xi \sim 10 \quad \text{for } qq\gamma$$





Z + γ Decay modes

- 95% CL upper limits on σ x BR(H→Zγ)

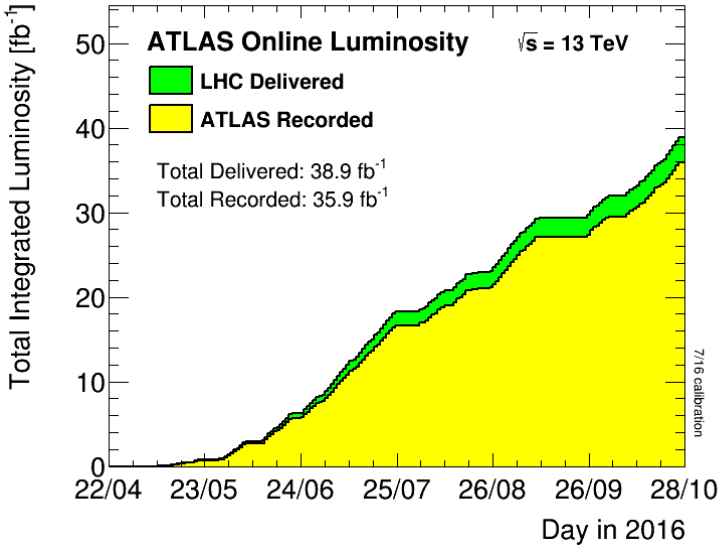


⇒ leptonic (hadronic) decay has better sensitivity at low (high) mass

Summary and Perspectives

- A Heavy Higgs boson has been searched for using up to 14.8 fb-1 @ 13 TeV in many diboson decay modes:
  - fully leptonic (ZZ→4l) including neutrinos (ZZ→llvv, WW→lvlv)
  - semi-hadronic (ZZ→llqq, vvqq, WW→lvqq)
  - with γs (γγ, Zγ→llγ, qqγ)
  - fully hadronic (VV→qqqq)
- No significant deviation has been found

  ⇒ Stringent upper limits have been set for:
  - ggF and VBF production modes
  - for NWA and LWA line shapes over a wide range



- The 2016 data taking is now complete with ~36.5 fb^{-1} available for physics from 2015/16 (more than x2.5 in statistics)

  ⇒ good perspective for discovery or more stringent contraints
  - work on-going to include interference effects

Backups

Interference Considerations

- Time has not allowed to include interference effects
  - It has been considered more important to include additional data
- Interference effects are in general small for the widths considered
  - The lower mass limit has in some cases been increase to avoid ~10% effects
- Planning to include interference effects for h, H and background for the spring publications
  - Will depend upon the H couplings, and so model-dependent